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CONTENTS.

Irrigation: COL. SIR C. SCOTT MONCRIEFF... 577

The American Anthropological Association: DR. GEORGE GRANT MACCURDY............ 591

Scientific Books:—
Gulick on Evolution, Racial and Habitudinal: PROFESSOR W. H. DALL. *Marcelli Nencki Opera Omnia:* PROFESSOR LAFAYETTE B. MENDEL. *Prost's Applied Chemical Analysis:* PROFESSOR JOSEPH W. RICHARDS. *Bourdeau on L'Histoire de l'habillement et de la parure:* O. T. M.................... 593

Scientific Journals and Articles............ 596

Societies and Academies:—
The Elisha Mitchell Scientific Society: ALVIN S. WHEELER....................... 597

Discussion and Correspondence:—
Musical Instruments of Malaysia and the West Coast of America: E. H. HAWLEY. *The Bureau of Soils:* ARTHUR JOHN HOPKINS 597

Special Articles:—
The Method of Elimination in Fixing Generic Types in Zoological Nomenclature: PRESIDENT DAVID STARR JORDAN. *An Interesting Cretaceous Chimæroid Egg-Case:* DR. THEO. GILL. *Electrometer for the Stage of the Microscope:* PROFESSOR W. T. PORTER 598

Quotations:—
Research Work in Great Britain......... 603

Falls of Meteors.......................... 604

The Massachusetts Institute of Technology and Harvard University................. 604

Scientific Notes and News.................. 604

University and Educational News........... 608

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IRRIGATION.[1]

SCIENCE has been defined as the medium through which the knowledge of the few can be rendered available to the many; and among the first to avail himself of this knowledge is the engineer. He has created a young science, the offspring, as it were, of the older sciences, for without them engineering could have no existence.

The astronomer, gazing through long ages at the heavens and laying down the courses of the stars, has taught the engineer where to find his place on the earth's surface.

The geologist has taught him where he may find the stones and the minerals which he requires, where he may count on firm rock beneath the soil to build on, where he may be certain he will find none.

The chemist has taught him of the subtle gases and fluids which fill all space, and has shown him how they may be transformed and transfused for his purposes.

The botanist has taught him the properties of all trees and plants, 'from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall.'

And all this knowledge would be as nothing to the engineer had he not reaped the fruits of that most severe of all pure and noble sciences—the science of numbers and dimensions, of lines and curves and spaces, of surfaces and solids—the science of mathematics.

Were I to attempt in the course of a single address to touch on all the many

[1] Address of the president to the Engineering Section of the British Association for the Advancement of Science, South Africa, 1905.

branches of engineering, I could do no more than repeat a number of platitudes, which you know at least as well as I do. You would probably have fallen asleep before I was half finished, and it would be the best thing you could do. I think, then, that it will be better to select one branch, a branch on which comparatively little has been written, which has, I understand, a special interest for South Africa, and which has occupied the best years of my life in India, southern Europe, central Asia and Egypt—I mean the science of irrigation. My subject is water—living, life-giving water. It can surely never be a dry subject; but we all know that with the best text to preach on the preacher may be as dry as dust.

IRRIGATION: WHAT IT MEANS.

Irrigation may be defined as the artificial application of water to land for the purposes of agriculture. It is, then, precisely the opposite of drainage, which is the artificial removal of water from lands which have become saturated, to the detriment of agriculture. A drain, like a river, goes on increasing as affluents join it. An irrigation channel goes on diminishing as water is drawn off it. Later on I shall show you how good irrigation should always be accompanied by drainage.

In lands where there is abundant rainfall, and where it falls at the right season of the year for the crop which it is intended to raise, there is evidently no need of irrigation. But it often happens that the soil and the climate are adapted for the cultivation of a more valuable crop than that which is actually raised, because the rain does not fall just when it is wanted, and there we must take to artificial measures.

In other lands there is so little rain that it is practically valueless for agriculture, and there are but two alternatives—irrigation or desert. It is in countries like these that irrigation has its highest triumph; nor are such lands always to be pitied or despised. The rainfall in Cairo is on an average 1.4 inch per annum, yet lands purely agricultural are sold in the neighborhood as high as £150 an acre.

This denotes a fertility perhaps unequaled in the case of any cultivation depending on rain alone, and this in spite of the fact that the Egyptian cultivator is in many respects very backward. The explanation is not far to seek. All rivers in flood carry along much more than water. Some carry alluvial matter. Some carry fine sand. Generally the deposit is a mixture of the two. I have never heard of any river that approached the Nile in the fertilizing nature of the matter borne on its annual floods; with the result that the plains of Egypt have gone on through all ages, with the very minimum of help from foreign manures, yielding magnificent crops and never losing their fertility. Other rivers bring down little but barren sand, and any means of keeping it off the fields should be employed.

PRIMITIVE MEANS OF IRRIGATION.

The earliest and simplest form of irrigation is effected by raising water from a lake, river or well, and pouring it over the land. The water may be raised by any mechanical power, from the brawny arms of the peasant to the newest pattern of pump. The earliest Egyptian sculptures show water being raised by a bucket attached to one end of a long pole, turning on an axis with a heavy counterpoise at the other end. In Egypt this is termed a *shadoof*, and to this day, all along the Nile banks, from morning to night, brown-skinned peasants may be seen watering their fields in precisely this way. Tier above tier they ply their work so as to raise water fifteen or sixteen feet on to their land. By this simple contrivance it

is not possible to keep more than about four acres watered by one *shadoof*, so you may imagine what an army is required to irrigate a large surface. Another method, largely used by the natives of northern India, is the shallow bucket suspended between two strings, held by men who thus bale up the water. A step higher is the water-wheel, with buckets or pots on an endless chain around it, worked by one or a pair of bullocks. This is a very ordinary method of raising the water throughout the East, where the water-wheel is of the rudest wooden construction and the pots are of rough earthenware. Yet another method of water-raising is very common in India from wells where the spring level may be as deep as one hundred feet or more. A large leathern bag is let down the well by a rope passing over a pulley and raised by a pair of bullocks, which haul the bag up as they run down a slope the depth of the well. An industrious farmer with a good well and three pairs of good bullocks can keep as much as twelve acres irrigated in northern India, although the average is much less there. The average cost of a masonry well in India varies from £20 to £40, according to the depth required. But it is obvious that in many places the geological features of the country are such that well-sinking is impracticable. The most favorable conditions are found in the broad alluvial plains of a deltaic river, the subsoil of which may be counted on as containing a constant supply of water.

PUMPS AND WINDMILLS.

All these are the primitive water-raising contrivances of the East. Egypt has of late been more in touch with Western civilization, and since its cotton and sugar-cane crops yield from £6 to £8, or even £10 per acre, the well-to-do farmer can easily afford a centrifugal pump worked by steam power. Of these there are now many hundreds fixed or portable working on the Nile banks in Egypt. Where wind can be counted on the windmill is a very useful and cheap means of raising water. But everything depends on the force and the reliability of the wind. In the dry western states of America wind power is largely used for pumping. It is found that this power is of little use if its velocity is not at least six miles per hour. (The mean force of the wind throughout the whole United States is eight miles per hour.) Every windmill, moreover, should discharge its water into a tank. It is evident that irrigation can not go on without cessation day and night, and it may be that the mill is pumping its best just when irrigation is least wanted. The water should, therefore, be stored till required. In America it is found that pumping by wind power is about two-thirds of the cost of steam power. With a reservoir five to fifteen acres may be kept irrigated by a windmill. Without a reservoir three acres is as much as should be counted on. Windmills attached to wells from 30 to 150 feet deep cost from £30 to £70.

ARTESIAN WELLS.

Up to now the artesian well can not be counted on as of great value for irrigation. In the state of California there are said to be 8,097 artesian wells, of a mean depth of 210 feet, discharge .12 cubic feet per second, and original cost on an average £50. Thirteen acres per well is a large outturn.

In Algeria the French have bored more than 800 artesian wells, with a mean depth of 142 feet, and they are said to irrigate 50,000 acres. But this is scattered over a large area. Otherwise, the gathering ground would probably yield a much smaller supply to each well than it now has. In Queensland artesian wells are largely used for the water supply of cattle stations, but not for irrigation.

WELL IRRIGATION.

It is evident that where water has to be raised on to the field there is an outlay of human or mechanical power which may be saved if it can be brought to flow over the fields by gravitation. But there is one practical advantage in irrigating with the water raised from one's own well or from a river. It is in the farmer's own hands. He can work his pump and flood his lands when he thinks best. He is independent of his neighbors, and can have no disputes with them as to when he may be able to get water and when it may be denied to him. In Eastern countries, where corruption is rife among the lower subordinates of government, the farmer who sticks to his well knows that he will not require to bribe any one; and so it is that in India about thirteen millions of acres, or 30 per cent. of the whole annual irrigation, is effected by wells. Government may see fit to make advances to enable the farmer to find his water and to purchase the machinery for raising it; or joint-stock companies may be formed with the same object. Beyond this all is in the hands of the landowner himself.

CANAL IRRIGATION.

Irrigation on a large scale is best effected by diverting water from a river or lake into an artificial channel, and thence on to the fields. If the water surface of a river has a slope of two feet per mile, and a canal be drawn from it with a surface slope of one foot per mile, it is evident that at the end of a mile the water in the canal will be one foot higher than that in the river; and if the water in the river is ten feet below the plain, at the end of ten miles the water in the canal will be flush with the plain, and henceforth irrigation can be effected by simple gravitation.

When there is no question of fertilizing deposit, and only pure water is to be had, the most favorable condition of irrigation is where the canal or the river has its source of supply in a great lake. For, be the rainfall ever so heavy, the water surface in the lake will not rise very much, nor will it greatly sink at the end of a long drought. Where there is no moderating lake, a river fed from a glacier has a precious source of supply. The hotter the weather, the more rapidly will the ice melt, and this is just when irrigation is most wanted.

Elsewhere, if crops are to be raised and the rain can not be counted on, nor well irrigation be practised, water storage becomes necessary, and it is with the help of water storage that in most countries irrigation is carried on.

WATER STORAGE.

To one who has not given the subject attention surprise is often expressed at the large volume of water that has to be stored to water an acre of land. In the case of rice irrigation in India, it is found that the storage of a million cubic feet does not suffice for more than from six to eight acres. For the irrigation of wheat about one third this quantity is enough. It would never pay to excavate on a level plain a hollow large enough to hold a million cubic feet of water. It is invariably done by throwing a dam across the bed of a river or a valley and ponding up the water behind it. Many points have here to be considered: The length of dam necessary, its height, the material of which it is to be constructed, the area and the value of the land that must be submerged, the area of the land that may be watered. The limits of the height of a dam are from about 150 to 15 feet. If the slope of the valley is great it may be that the volume which can be ponded up with a dam of even 150 feet is inconsiderable, and the cost may be prohibitory. On the other hand, if the country is very flat, it may be that a dam of only 20 feet high may require to be of quite an inor-

dinate length, and compensation for the area of land to be submerged may become a very large item in the estimate. I have known of districts so flat that in order to irrigate an acre more than an acre must be drowned. This looks ridiculous, but is not really so, for the yield of an irrigated acre may be eight or ten times that of an unirrigated one; and after the storage reservoir has been emptied it is often possible to raise a good crop on the saturated bed.

The advantage of a deep reservoir is, however, very great, for the evaporation is in proportion to the area of the surface, and if two reservoirs contain the same volume of water, and the depth of one is double that of the other, the loss by evaporation from the shallow one will be double that of the deep one. In India, from time immemorial, it has been the practise to store water for irrigation, and there are many thousands of reservoirs, from the great artificial lakes holding as much as 5,000 or 6,000 millions of cubic feet, down to the humble village tank holding not a million. There are few of which the dam exceeds 80 feet in height, and such are nearly always built of masonry or concrete. For these it is absolutely necessary to have sound rock foundations. If the dam is to be of earth, the quality of the soil must be carefully seen to, and there should be a central core of puddle resting on rock and rising to the maximum height of water surface. If the dam is of masonry, there may perhaps be no harm done should the water spill over the top. If it is of earth, this must never happen, and a waste weir must be provided, if possible cut out of rock or built of the best masonry, and large enough to discharge the greatest possible flood. More accidents occur to reservoirs through the want of sufficient waste weirs or their faulty construction than from any other cause.

As important as the waste weir are the outlet sluices through which the water is conveyed for the irrigation of the fields. If possible they should be arranged to serve at the same time as scouring sluices to carry off the deposit that accumulates at the bottom of the reservoir. For, unless provided with very powerful scouring sluices, sooner or later the bed of the reservoir will become silted up, and the space available for water storage will keep diminishing. As this happens in India, it is usual to go on raising the embankment (for it does not pay to dig out the deposit), and so the life of a reservoir may be prolonged for many years. Ultimately it is abandoned, as it is cheaper to make a new reservoir altogether than to dig out the old one.

ITALIAN IRRIGATION.

For the study of high-class irrigation there is probably no school so good as is to be found in the plains of Piedmont and Lombardy. Every variety of condition is to be found here. The engineering works are of a very high class, and from long generations of experience the farmer knows how best to use his water.

The great river Po has its rise in the foothills to the west of Piedmont. It is not fed from glaciers, but by rain and snow. It carries with it a considerable fertilizing matter. Its temperature is higher than that of glacial water—a point to which much importance is attached for the very valuable meadow irrigation of winter. From the left bank of the Po, a few miles below Turin, the great Cavour Canal takes its rise, cutting right across the whole drainage of the country. It has a full-supply discharge of 3,800 cubic feet per second; but it is only from October to May that it carries anything like this volume. In summer the discharge does not exceed 2,200 cubic feet per second, which would greatly cripple the value of the work were

it not that the glaciers of the Alps are melting then, and the great torrents of the Dora Baltea and Sesia can be counted on for a volume exceeding 6,000 cubic feet per second.

Lombardy is in no respect worse off than Piedmont for the means of irrigation; and its canals have the advantage of being drawn from the lakes Maggiore and Como, exercising a moderating influence on the Ticino and Adda Rivers, which is sadly wanted on the Dora Baltea. The Naviglio Grande of Lombardy is drawn from the left bank of the Ticino, and is used largely for navigation, as well as irrigation. It discharges between 3,000 and 4,000 cubic feet per second, and nowhere is irrigation probably carried on with less expense. From between Lake Maggiore and the head of the Naviglio Grande a great new canal, the Villoresi, has been constructed during the last few years with head sluices capable of admitting 6,700 cubic feet per second, of which, however, 4,200 cubic feet have to be passed on to the Naviglio Grande. Like the Cavour Canal, the Villoresi crosses all the drainage coming down from the foothills to the north. This must have entailed the construction of very costly works.

IRRIGATION IN NORTHERN INDIA.

It is in India that irrigation on the largest scale is to be found. The great plains of northern India are peculiarly well adapted for irrigation, which is a matter of life and death to a teeming population all too well accustomed to a failure of the rain supply.

The Ganges, the Jumna and the great rivers of the Punjab have all been largely utilized for feeding irrigation canals. The greatest of these, derived from the river Chenab, and discharging from 10,500 to 3,000 cubic feet per second, was begun in 1889, with the view of carrying water into a tract entirely desert and unpopulated. It was opened on a small scale in 1892, was then enlarged, and ten years after it irrigated in one year 1,829,000 acres, supporting a population of 800,000 inhabitants, colonists from more congested parts of India.

The Ganges Canal, opened in 1854, at a time when there was not a mile of railway, and hardly a steam engine within a thousand miles, has a length of about 9,900 miles, including distributing channels. It was supplemented in 1878 by a lower canal, drawn from the same river 130 miles further down, and these two canals now irrigate between them 1,700,000 acres annually. On all these canals are engineering works of a very high class. The original Ganges Canal, with a width of bed of 200 feet, a depth of ten feet, and a maximum discharge of 10,000 cubic feet per second, had to cross four great torrents before it could attain to the watershed of the country, after which it could begin to irrigate. Two of these torrents are passed over the canal by broad super-passages. Over one of them the canal is carried in a majestic aqueduct of fifteen arches, each of fifty feet span; and the fourth torrent, the most difficult of all to deal with, crosses the canal at the same level, a row of forty-seven floodgates, each ten feet wide, allowing the torrent to pass through and out of the canal.

Elsewhere there are rivers in India, rising in districts subject to certain heavy periodical rainfall, and carrying their waters on to distant plains of very uncertain rainfall. At a small expense channels can sometimes be constructed drawing off from the flooded river water sufficient thoroughly to saturate the soil, and render it fit to be ploughed up and sown with wheat or barley, which do not require frequent watering. The canal soon dries up, and the sown crop must take its chance; but a timely shower of rain may come in to help it, or well irrigation

may mature the crop. These, which are known in India as inundation canals, are of high value.

SOUTHERN INDIA.

In southern India there are three great rivers, drawing their supply from the line of hills called the Ghats, running parallel to and near the western coast, and after a long course discharging into the Bay of Bengal on the east coast. Against the Ghats beats the whole fury of the tropical southwest monsoon, and these rivers for a few months are in high flood. As they approach the sea they spread out in the usual deltaic form. Dams have been built across the apex of these deltas, from which canals have been drawn, and the flood waters are easily diverted over the fields, raising a rice crop of untold value in a land where drought and famine are too common. But for the other months of the year these rivers contain very little water, and there is now a proposition for supplementing them with very large reservoirs.

A very bold and successful piece of irrigation engineering was carried out a few years ago in south India, which deserves notice. A river named the Periyar took its rise in the Ghats, and descended to the sea on the west coast, where there was no means of utilizing the water, and a good deal of money had periodically to be spent in controlling its furious floods. A dam has now been built across its course, and a tunnel has been made through the mountains, enabling the reservoir to be discharged into a system of canals to the east, where there is a vast plain much in need of water.

In the native state of Mysore, in southern India, there are on the register about 40,000 irrigation reservoirs (or tanks, as they are called), or about three to every four square miles, and the nature of the country is such that hundreds may be found in the basin of one river—small tanks in the upper branches and larger ones in the lower, as the valley widens out, and these require constant watchful attention. From time to time tropical rainstorms sweep over the country. If then even a small tank has been neglected, and rats and porcupines have been allowed to burrow in the dam, the flood may burst through it, and sweep on and over the dam of the next village, lower down. One dam may then burst after another, like a pack of cards, and terrible loss occurs.

In this state of Mysore a very remarkable irrigation reservoir is now under construction at a place called Mari Kanave. Nature seems here to have formed an ideal site for a reservoir, so that it is almost irresistible for the engineer to do his part, even although irrigation is not so badly wanted here as elsewhere. The comparatively narrow neck of a valley containing 2,075 square miles is being closed by a masonry dam 142 feet high. The reservoir thus formed will contain 30,000 million cubic feet of water, but it is not considered that it will fill more than once in thirty years. Nor is there irrigable land requiring so great a volume of water. Much less would be sufficient, so such a high dam is not needed; but the construction of a waste weir to prevent the submergence of a lower dam would require such heavy excavation through one of the limiting hills that it is cheaper to raise the dam and utilize a natural hollow in the hillside for a waste weir.

IRRIGATION IN EGYPT.

No lecture on irrigation would be complete without describing what has been done in Egypt. You are generally familiar with the shape of that famous little country. Egypt proper extends northwards from a point in the Nile about 780 miles above Cairo—a long valley, never eight miles wide, sometimes not a half a mile.

East and west of this lies a country broken into hills and valleys, wild crags, level stretches, but everywhere absolutely sterile, dry sand and rock, at such a level that the Nile flood has never reached it to cover its nakedness with fertile deposit. A few miles north of Cairo the river bifurcates, and its two branches flow each for about 130 miles to the sea. As you are probably aware, with rivers in a deltaic state the tendency is for the slope of the country to be away from the river, and not towards it. In the Nile Valley the river banks are higher than the more distant lands. From an early period embankments were formed along each side of the river, high enough not to be topped by the highest flood. At right angles to these river embankments others were constructed, dividing the whole valley into a series of oblongs, surrounded on three sides by embankments, on the fourth by the desert heights. These oblong areas vary from about 50,000 to 3,000 acres. I have said the slope of the valley is away from the river. It is easy, then, when the Nile is low, to cut short deep canals in the river banks, which fill as the river rises and carry the precious mud-charged water into these great flats. There the water remains for a month or more, some three or four feet deep, depositing its mud, and then at the end of the flood it may either be run off direct into the receding river, or cuts may be made in the cross embankments and the water passed off one flat after another, and finally rejoin the river. This takes place in November, when the river is rapidly falling. Whenever the flats are firm enough to allow a man to walk over them with a pair of bullocks, the mud is roughly turned over with a wooden plough, or even the branch of a tree, and wheat or barley is immediately sown. So soaked is the soil after the flood that the seed germinates, sprouts and ripens in April without a drop of rain or any more irrigation, except what, perhaps, the owner may give from a shallow well dug in the field. In this manner was Egypt irrigated up to about a century ago. The high river banks which the flood could not cover were irrigated directly from the river, the water being raised as I have already described.

THE BARRAGE.

With the last century, however, appeared a very striking figure in Egyptian history, Muhammed Ali Pasha, who came from Turkey a plain captain of infantry, and before many years had made himself master of the country, yielding only a very nominal respect to his suzerain lord, the Sultan, at Constantinople.

Muhammed Ali soon recognized that with this flood system of irrigation only one cereal crop was raised in the year, while with such a climate and such a soil, with a teeming population and with the markets of Europe so near, something far more valuable might be raised. Cotton and sugar-cane would fetch far higher prices; but they could only be grown at a season when the Nile is low, and they must be watered at all seasons. The water-surface at low Nile is about twenty-five feet below the flood-surface, or more than twenty feet below the level of the country A canal, then, running twelve feet deep in the flood would have its bed thirteen feet above the low-water surface. Muhammed Ali ordered the canals in lower Egypt to be deepened; but this was an enormous labor, and as they were badly laid out and graded they became full of mud during the flood and required to be dug out afresh. Muhammed Ali was then advised to raise the water-surface by erecting a dam (or, as the French called it, a *barrage*) across the apex of the delta, twelve miles north of Cairo, and the result was a very costly and imposing work, which it took long years and untold wealth to construct, and which

was no sooner finished than it was condemned as useless.

EGYPTIAN IRRIGATION SINCE THE ENGLISH OCCUPATION.

With the English occupation in 1883 came some English engineers from India, who, supported by the strong arm of Lord Cromer, soon changed the situation. The first object of their attention was the *barrage* at the head of the delta, which was made thoroughly sound in six years and capable of holding up fifteen feet of water. Three great canals were taken from above it, from which a network of branches are taken, irrigating the province to the left of the western, or Rosetta branch of the river, the two provinces between the branches, and the two to the right of the eastern, or Damietta branch.

In upper Egypt, with one very important exception (the Ibrahimieh Canal, which is a perennial one), the early flood system of irrigation, yielding one crop a year, prevailed until very recently, but it was immensely improved after the British occupation by the addition of a great number of masonry head sluices, aqueducts, escape weirs, etc., on which some £800,000 was spent. With the completion of these works, and of a complete system of drainage, to be alluded to further on, it may be considered that the irrigation system of Egypt was put on a very satisfactory basis. There was not much more left to do, unless the volume of water at disposal could be increased.

Probably no large river in the world is so regular as the Nile in its periods of low supply and of flood. It rises steadily in June, July and August. Then it begins to go down, at first rapidly, then slowly, till the following June. It is never a month before its time, never a month behind. It is subject to no exceptional floods from June to June. Where it enters Egypt the difference between maximum and minimum Nile is about twenty-five feet. If it rises three and one half feet higher the country is in danger of serious flooding. If its rise is six feet short of the average there existed in former days a great risk that the floods would never cover the great flats of upper Egypt, and thus the ground would remain as hard as stone, and sowing in November would be impossible. Fortunately the good work of the last twenty years very much diminishes this danger.

THE ASSUAN DAM AND RESERVOIR.

In average years the volume of water flowing past Cairo in September is from thirty-five to forty times the volume in June. Far the greater part of this flood flows out to the sea useless. How to catch and store this supply for use the following May and June was a problem early pressed on the English engineers in Egypt.

During the time of the highest flood the Nile carries along with it an immense amount of alluvial matter, and when it was first proposed to store the flood-water the danger seemed to be that the reservoir would in a few years be filled with deposit, as those I have described in India. Fortunately it was found that after November the water was fairly clear, and that if a commencement were made even as late as that there would still be water enough capable of being stored to do enormous benefit to the irrigation.

A site for a great dam was discovered at Assuan, 600 miles south of Cairo, where a dyke of granite rock crosses the valley of the river, occasioning what is known as the First Cataract. On this ridge of granite a stupendous work has now been created. A great wall of granite 6,400 feet long has been thrown across the valley, 23 feet thick at the crest, 82 feet at the base. Its height above the rock-bed of the river is 130 feet. This great wall or dam holds up a depth

of 66 feet of water, which forms a lake of more than 100 miles in length up the Nile Valley, containing 38,000 million cubic feet of water.

The dam is pierced with 180 sluices, or openings, through which the whole Nile flood, about 360,000 cubic feet per second, is discharged. A flight of four locks, each 260 by 30 feet, allows of free navigation past the dam. The foundation-stone of this great work was laid in February 1899, and it was completed in less than four years. At the same time a very important dam of the pattern of the barrage north of Cairo was built across the Nile at Assiut, just below the head of the Ibrahimieh Canal, not with the object of storing water, but to enable a requisite supply at all times to be sent down that canal.

The chief use of the great Assuan reservoir is to enable perennial irrigation, such as exists in lower Egypt, to be substituted in upper Egypt for the basin system of watering the land only through the Nile flood; that is, to enable two crops to be grown instead of one every year, and to enable cotton and sugar-cane to take the place of wheat and barley. But a great deal more had to be done in order to obtain the full beneficial result of the work. About 450,000 acres of basin irrigation are now being adapted for perennial irrigation. Many new canals have had to be dug, others to be deepened. Many new masonry works have had to be built. It is probable the works will be finished in 1908. There will then have been spent on the great dam at Assuan, the minor one at Assiut, and the new canals of distribution in upper Egypt about six and a half millions sterling. For this sum the increase of land rental will be about £2,637,000, and its sale value will be increased by about £26,570,000.

DRAINAGE.

In the great irrigation systems which I have been describing for a long time little or no attention was paid to drainage. It was taken for granted that the water would be absorbed, or evaporated, and get away somehow without doing any harm. This may hold good for high-lying lands, but alongside of these are low-lying lands, into which the irrigation water from above will percolate and produce waterlogging and marsh. Along with the irrigation channel should be constructed the drainage channel, and Sir W. Willcocks, than whom there is no better authority on this subject, recommends that the capacity of the drain should be one third that of the canal. The two should be kept carefully apart—the canal following the ridges, the drain following the hollows of the country, and one in no case obstructing the other. This subject of drainage early occupied the attention of the English engineers in Egypt. In the last twenty years many hundred miles of drains have been excavated, some as large as 50 feet width of bed and 10 feet deep.

IRRIGATION IN AMERICA.

If it is to Italy that we should look for highly finished irrigation works and careful water distribution, and to India and Egypt for widespreading tracts of watered land, it is to America that we naturally look for rapid progress and bold engineering. In the western states of America there is a rainfall of less than 20 inches per annum, the consequence of which is a very rapid development of irrigation works. In 1889 the irrigation of these western states amounted to 3,564,416 acres. In 1900 it amounted to 7,539,545 acres. Now it is at least 10,000,000 acres. The land in these states sells from 10s. to £1 per acre if unirrigated. With irrigation the same land fetches £8 10s. per acre. The works are often rude and of a temporary nature, the extensive use of timber striking a foreigner from the old world. Some of the

American canals are on a large scale. The Idaho Company's canal discharges 2,585 cubic feet, the Turlook Canal in California 1,500 cubic feet, and the North Colorado Canal 2,400 cubic feet per second. These canals have all been constructed by corporations or societies, in no case by government. On an average it has cost about 32s. per acre to bring the water on to the land, and a water-rate is charged of from £2 8s. to £4 per acre, the farmer paying in addition a rate of from 2s. to 10s. per acre annually for maintenance. Distributary channels of less than five feet wide cost less than £100, up to ten feet wide about £150 per mile.

THE INTRODUCTION OF IRRIGATION INTO A COUNTRY.

It is evident that there are many serious considerations to be taken into account before entering on any large project for irrigation. Statistics must be carefully collected of rainfall, of the sources of water supply available, and of the amount of that rainfall which it is possible to store and utilize. The water should be analyzed if there is any danger of its being brackish. Its temperature should be ascertained. It should be considered what will be the effect of pouring water on the soil, for it is not always an unmixed benefit. A dry climate may be changed into a moist, and fever and ague may follow. In India there are large tracts of heavy black soil, which with the ordinary rainfall produce excellent crops nine years out of ten, and where irrigation would rather do harm than good. But in the tenth year the rains fail, and without artificial irrigation the soil will yield nothing. So terrible may be the misery caused by that tenth year of drought that even then it might pay a government to enter on a scheme of irrigation. But it is evident that it might not pay a joint-stock company.

In all cases it is of the first importance to establish by law the principle that all rivers or streams above a certain size are national property, to be utilized for the good of the nation. Even where there is no immediate intention of constructing irrigation works it is well to establish this principle. Otherwise vested rights may be allowed to spring up, which it may be necessary in after years to buy out at a heavy cost.

MODES OF DISTRIBUTING AND ASSESSING WATER.

Where the river is too inconsiderable to be proclaimed as national property, and where there is no question of spreading the water broadcast over the land, but of bestowing it with minute accuracy over small areas to rear valuable plants, such as fruit-trees, it may be very well left to local societies or to syndicates of farmers to manage their own affairs. Where irrigation is on a larger scale, and its administration is a matter of national importance, the control of the water requires the closest consideration, especially if, as is usually the case, the area which may be irrigated exceeds the volume of water available to irrigate it, and where the water is delivered to the fields by gravitation without the labor of raising it. It must be decided on what principle the farmer's right to the water is to be determined. Is he to obtain water in proportion to the area of his land which is irrigable? If part of the irrigable land is not yet cultivated, is some of the supply to be reserved for such land? Is he to pay in proportion to the area actually watered for each crop, or to the area which he might water if he chose? Where the slope of the land is sufficient to allow the water to flow freely out of a sluice into the field channel, it is not difficult to measure the water discharged. Modules have been invented for this purpose, and the owner of the field may

be required to pay for so many cubic feet of water delivered. The government or the association owning the canal will then have nothing to do with the way in which the water is employed, and self-interest will force the farmer to exercise economy in flooding his land. But even then precautions must be taken to prevent him from keeping his sluice open when it should be shut.

In Italy and in America water is generally charged by the module; but in many cases, where the country is very flat, the water can not fall with a free drop out of the sluice, and, as far as I know, no satisfactory module has yet been invented for delivering a constant discharge through a sluice when the head of water in the channel of supply is subject to variation. These are the conditions prevailing in the plains of northern India, where there is a yearly area of canal irrigation of about six millions of acres. The cultivator pays not in proportion to the volume of water he uses, but on the area he waters every crop, the rate being higher or lower according as the nature of the crop demands more or less water.

The procedure of charging for water is, then, as follows: When the crop is nearly ripe the canal watchman, with the village accountant and the farmers interested, go over the fields with a government official. The watchman points out a field which he says has been watered. The accountant, who has a map and field-book of the village, states the number and the area of the field and its cultivator. These are recorded along with the nature of the crop watered. If the cultivator denies that he has received water, evidence is heard and the case is settled. A bill is then made out for each cultivator, and the amount is recovered with the taxes.

This system is perfectly understood, and works fairly well in practise. But it is not a satisfactory one. It holds out no inducement to the cultivator to economize water, and it leaves the door open to a great deal of corruption among the canal watchmen and the subordinate revenue officials.

GOVERNMENT CONTROL OF WATER SUPPLY.

Where the subject agricultural population is unfitted for representative government it is best that the government should construct and manage the irrigation, on rules carefully considered and rigorously enforced, through the agency of officers absolutely above suspicion of corruption or unfair dealing. Such is the condition in Egypt and in the British possessions in India. Objections to it are evident enough. Officials are apt to be formal and inelastic, and they are often far removed from any close touch with the cultivating classes. But they are impartial and just, and I know of no other system that has not still greater defects.

Even if the agricultural classes in India were much better educated than they are, it would still be best that the control of the irrigation should rest with the government. By common consent it is the government alone that rules the army. Now the irrigation works form a great army, of which the first duty is to fight the grim demon of famine. Their control ought, therefore, to rest with the government; but the conditions are very different when the agricultural classes are well educated and well fitted to manage their own affairs.

Irrigation is too new and experimental in America for us to look there for a well-devised scheme of water control. The laws and rules on the subject vary in different states, and are often contradictory. It is better to look at the system evolved after long years in north Italy.

THE ITALIAN SYSTEM.

I have already alluded to the great

Cavour Canal in Piedmont. This fine work was constructed by a syndicate of English and French capitalists, to whom the government gave a concession in 1862. Circumstances to which I need not allude ruined this company, and the government, who already had acquired possession of many other irrigation works in Piedmont, took over the whole Cavour Canal in 1874, a property valued at above four millions sterling, and ever since the government has administered it.

The chief interest of this administration centers on the Irrigation Association west of the Sesia,[2] an association that owes its existence to the great Count Cavour. It takes over from the government the control of all the irrigation effected by the Cavour and other minor canals within a great triangle lying between the left bank of the Po and the right bank of the Sesia. The association purchases from the government from 1,250 to 1,300 cubic feet per second. In addition to this it has the control of all the water belonging to private canals and private rights, which it purchases at a fixed rate. Altogether it distributes about 2,275 cubic feet per second, and irrigates therewith about 141,000 acres, of which rice is the most important crop. The association has 14,000 members, and controls 9,600 miles of distributary channels. In each parish is a council, or, as it is called, a *consorzio,* composed of all landowners who take water. Each *consorzio* elects one or two deputies, who form a sort of water parliament. The deputies are elected for three years, and receive no salary. The assembly of deputies elects three committees—the direction-general, the committee of surveillance, and the council of arbitration. The first of these committees has to direct the whole distribution of the waters, to see to the conduct of the employees, etc. The committee of surveillance has to see that the direction-general does its duty. The council of arbitration, which consists of three members, has most important duties. To it may be referred every question connected with water-rates, all disputes between members of the association or between the association and its servants, all cases of breaches of rule or of discipline. It may punish by fines any member of the association found at fault, and the sentences it imposes are recognized as obligatory, and the offender's property may be sold up to carry them into effect. An appeal may be made within fifteen days from the decisions of this council of arbitration to the ordinary law courts, but so popular is the council that, as a matter of fact, such appeals are never made.

[2] See Mr. Elwood Mead's 'Report on Irrigation in Northern Italy,' printed for the Department of Agriculture, Washington, 1904.

To effect the distribution of the water the area irrigated is divided into districts, in each of which there is an overseer in charge and a staff of guards to see to the opening and closing of the modules which deliver the water into the minor watercourses. In November of each year each parish sends in to the direction-general an indent of the number of acres of each description of crop proposed to be watered in the following year. If the water is available the direction-general allots to each parish the number of modules necessary for this irrigation; but it may quite well happen that the parish may demand more than can be supplied, and may have to substitute a crop like wheat, requiring little water, for rice, which requires a great deal.

The government executes and pays for all repairs on the main canals. It further executes, at the cost of the Irrigation Association, all repairs on the minor canals. The association, then, has no engineers in its employ, but a large staff of irrigators.

The irrigation module employed in Piedmont is supposed to deliver 2.047 cubic feet per second. The association west of the Sesia buys from the government what water it requires at a rate fixed at 800 liras per module, or £15 12s. 7d. per cubic foot per second per annum.

The association distributes the water by module to each district, and the district by module to each parish. Inside the parish each farmer pays, according to the area he waters, a sum to cover all the cost of the maintenance of the irrigation system, and his share of the sum which the association has to pay to the government. This sum varies from year to year according as the working expenses of the year increase or diminish.

I have already mentioned the recently constructed Villoresi Canal in Lombardy. This canal belongs to a company, to whom the government have given large concessions. This company sells its water wholesale to four districts, each having its own secondary canal, the cubic meter per second, or 35.31 cubic feet per second, being the unit employed. These districts, again, retail the water to groups of farmers termed *comizios,* whose lands are watered by the same distributary channels, their unit being the liter, or .035 cubic foot per second. Within the *comizio* the farmer pays according to the number of hours per week that he has had the full discharge of the module.

I have thought it worth while to describe at some length the systems employed on these Italian canals, for the Italian farmers set a very high example, in the loyal way in which they submit to regulations which there must at times be a great temptation to break. A sluice surreptitiously opened during a dark night, and allowed to run for six hours, may quite possibly double the value of the crop which it waters. It is not an easy matter to distribute water fairly and justly between a number of farms at different levels, dependent on different watercourses, cultivating different crops. But in Piedmont this is done with such success that an appeal from the council of arbitration to the ordinary law courts is unheard of. It is thought apparently as discreditable to appropriate an unfair supply of water as to steal a neighbor's horse, as discreditable to tamper with the lock of the water module as with the lock of a neighbor's barn.

MR. SCHUYLER'S VIEWS AS TO GOVERNMENT CONTROL.

Where such a high spirit of honor prevails I do not see why syndicates of farmers should not construct and maintain a good system of irrigation. Nevertheless, I believe it is better that government should take the initiative in laying out and constructing the canals and secondary channels at least. A recent American author, Mr. James Dix Schuyler, has put on record: "That storage reservoirs are a necessary and indispensable adjunct to irrigation development, as well as to the utilization of power, requires no argument to prove. That they will become more and more necessary to our western civilization is equally sure and certain; but the signs of the times seem to point to the inevitable necessity of governmental control in their construction, ownership and administration."

This opinion should not be disregarded. Sir W. Willcocks has truly remarked: "If private enterprise can not succeed in irrigation works of magnitude in America, it will surely not succeed in any other country in this world." What its chances may be in South Africa I leave to my hearers to say. It is not a subject on which a stranger can form an opinion.

C. Scott Moncrieff.